Fermi National Accelerator Laboratory

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CDF

The Two-Jet Differential Cross-Section at CDF

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Abstract

Results for production of two or more hadronic jets at $\sqrt{s} = 1800$ GeV at the Fermilab Tevatron are presented. The data are compared with the results predicted by perturbative QCD. Ratios of cross-sections are also given.

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INTRODUCTION

We report a preliminary measurement of the differential cross-section for production of two energetic jets at $\sqrt{s} = 1800$ GeV. This measurement should provide a sensitive test of Next-to-Leading Order (NLO) QCD, which must predict the absolute normalizations and shapes of the cross-section over a wide range of the kinematic variables E_T and jet psueudo rapidity. It is expected that this measurement, or straightforward extensions of it, will provide a useful tool for probing the parton distribution functions. The measurement is complementary to the measurement of the dijet CM angular distribution [1] , which probes the vector nature of the gluon and is largely free of structure-function effects.

This analysis will use greatly improved statistics to perform a significant extension of previous CDF published work [2]. We also have structured the analysis to be readily comparable with NLO calculations.

METHODOLOGY

The process $\bar{p}p \longrightarrow$ jet1 + jet2 + X may be described by the differential cross section $\frac{d^3\sigma}{dE_t\, d\eta_1 d\eta_2}$, where η_1 and η_2 are the pseudo-rapidities of the two leading jets and E_T is the transverse energy of the leading jet. We use the variables η_1, η_2, and E_T instead of the related set y_1, y_2, and P_T, in order to establish a direct connection with experimentally measured quantities.

In this analysis we assign the two leading jets in E_T to categories of "trigger" jet (used to measure approximate E_T of the dijet system), and "probe" jet (used to measure pseudo-rapidity). Trigger jets are restricted to the region covered by the CDF Central Calorimeter [3] to benefit from the well-understood resolution of that detector for hadronic jets [4]. This restriction is not applied to probe jets. The cross-section formed from trigger jet-probe jet combinations is an approximation to the cross-section for jet production, doubly differential in E_T of the dijet system and η of the probe jet, with a central trigger jet ($\eta = 0$).

QCD radiation in the forms of additional jets and soft kicks in system transverse momentum can broaden the observed distributions of jet pseudo-rapidity and distort the shape of the differential cross-section. In what follows we do not attempt to correct the data to compare with a lowest-order theoretical model, preferring to leave the data in a form that can be directly compared with NLO theory which should predict the effects of additional radiation. We can in this way exploit the good η resolution of the CDF detector. We therefore fix the $|\eta|$ of the probe jet to be the measured $|\eta|$. We then form a family of trigger jet E_T spectra for each bin of probe jet $|\eta|$. These observed E_T spectra can be deconvolved from detector effects with conventional means previously used for our published results on the inclusive E_T spectra and X_T scaling [4,5].

DATA SET AND EVENT SELECTION

The data used in this analysis was collected in the 1992-93 run of the Fermilab Tevatron. Four inclusive single jet triggers, with hardware thresholds in measured E_T of 20, 50, 70, and 100 GeV, were combined to measure a large range of jet E_T. The luminosities used for the different triggers sets were:

100 GeV trigger	8.4 pb^{-1}
70 GeV trigger	9.8 pb^{-1}
50 GeV trigger	8.7 pb^{-1}
20 GeV trigger	9.4 pb^{-1}

Events were taken with prescale factors of 500, 20, 6, and 1 for the 20, 50, 70, and 100 GeV triggers, respectively.

The total number of events (before cuts) considered for the various samples was:

100 GeV trigger	45,661
70 GeV trigger	51,283
50 GeV trigger	72,850
20 GeV trigger	182,988

We make additional cuts on the E_T of the trigger jet at 35, 70, 100, and 125 GeV for the four samples. Events from the 20 GeV trigger are used to form the cross-section in the E_T range 35-70 GeV, events from the 50 GeV trigger in the range 70-100 GeV, etc. Trigger overlaps for the band of trigger jet η_1, $0.1 < |\eta_1| < 0.7$ provided verification that our triggers were efficient at the thresholds applied.

Events are next required to have $|z_{vert}| < 60$ cm and a value of (Missing E_T / Total E_T) < 0.45. The latter cut is motivated by the presence of residual background in the sample from cosmic rays and accelerator losses. Studies of the jet electromagnetic fraction (EMF) before and after the cut show a strong correlation, with rejected events having values of the EMF near 1.0 or 0.0. We estimate the residual events removed by the Missing E_T cut and **not** in the ranges EMF < 0.05 or EMF > 0.95 to be approximately 2% of the total sample.

RAW CROSS-SECTION

We form the raw differential cross-section as follows: In each event the two highest-E_T jets are examined for their suitability as a trigger jet by comparison with the applicable E_T threshold. In addition, the trigger jet is required to fall in the range $0.1 < |\eta_1| < 0.7$. If the first jet passes, its E_T is entered into a binned E_T histogram; the choice of histogram depends on the pseudo-rapidity of the second jet, $|\eta_2|$. We use slices in $|\eta_2|$ of 0.1-0.7, 0.7-1.2, 1.2-1.6, 1.6-2.0 and 2.0-3.0. These were chosen on the basis of statistics. The above process is repeated with the second jet playing the role of trigger jet and the leading E_T jet used to specify $|\eta_2|$. In both cases the jet specifying η_2 is required to have a minimum (measured) E_T of at least 10 GeV. All jets are corrected to the energy scale of the central calorimeter, to minimize relative ordering problems which could occur due to varying E_t scales in the regions covered by gas calorimetry, and in the regions between calorimeters.

CORRECTED CROSS-SECTION

The raw inclusive jet E_T spectra were corrected for detector effects (calorimeter energy loss and resolution). The correction procedure we employed was identical to that used for our earlier inclusive jet analyses. Our justification for applying these corrections to the new data comes from the good agreement seen in the raw jet cross-sections for the two runs (typically <10%). The systematic error on the corrected cross-sections is discussed below. Figure 1 shows the corrected cross-sections for various bins of $|\eta_2|$ together with the results of a Leading Order QCD calculation using MT-LO structure functions with $Q^2=E_T^2$. Only statistical errors are plotted on the points.

To quantify the differences seen in the E_T spectra as a function of second-jet η, we form the ratios of the spectra to the spectrum for the first η slice ($0.1 < |\eta_1| < 0.7$). This also has the advantage of providing a measured quantity with minimal systematic error, and one which is relatively insensitive to various theoretical uncertainties (such as choice of Q^2 scale). Figure 2 shows the four ratios constructed from our data-sets. Also shown are a set of Lowest Order QCD calculations using the LO-evolved MT structure function and $Q^2=E_T^2$.

SYSTEMATICS

At the present stage of the analysis, the systematic error on the jet cross-sections has been estimated using an approximate method. A full analysis of the systematic uncertainty will be performed once the entire data set is analysed.

The approximation technique starts with the full systematic uncertainty established for the inclusive central jet cross-section , excluding the normalization error from luminosity. This overall uncertainty is on the corrected jet cross-section, and is a function of corrected jet E_t. The uncertainty on cross-section was converted into an effective uncertainty on jet E_t scale by using the local slope of the inclusive jet cross-section. We then applied this effective E_t uncertainty (itself a function of E_t) to the cross-sections of this analysis, coverting to cross-section error using the new local slopes. This procedure has allowed us to transfer the known systematic error of our earlier published work [4] to the present analysis, by accounting for the fact that our spectra are of different steepnesses than the overall inclusive spectrum. Like the inclusive jet result, the systematic error bars of this analysis are asymmetric. The range of systematic error is +12/-18% to +32/-43%, and depends on $|\eta_2|$ and trigger jet E_T, being largest where the E_T spectra are steepest.

Systematic uncertainty on the ratio of cross-sections was determined by re-evaluating the ratio using cross-sections shifted up (down) by one positive (negative) systematic standard deviation. This implicitly assumes that the systematic errors on two cross-sections at the same E_t are 100% correlated. (Please note that, although 100% correlated, the errors will not cancel in the ratio unless their percentage magnitudes are the same; and this will only be the case when the numerator and denominator cross-sections have the same local slope, which is clearly not true everywhere for our data). The resulting systematic error on the four ratios spans, in order of increasing $|\eta_2|$ in the numerator, the following range (from lowest E_t to highest E_t): <1% to 5%; <1% to 7%; 1-20%; and 3-37%. One can see that in the low E_t region, where the slopes of the cross-sections are the most similar, the systematic error largely cancels in the ratio.

The distribution of probe jet η shows, at E_t less than 60 GeV, residual effects of cracks in the regions between instrumented regions, in the form of small visible depressions in the distribution. The effect is at least partially attributable to the effects of incorrect jet ordering arising from differences of measurered E_t scale in the gas and central calorimetry. (If the third jet arising from gluon radiation is identified as the second jet, it can in principle have a differing η distribution). Correction of the relative jet energy scales can correct the means of the distributions, reducing the problem, but one may still be affected by fluctuations. In practice, the application of mapping corrections decreases the effect significantly (at least

50% and more at some η). We assign an additional uncertainty from this effect to all η-slices except the central of 12% in the region 35 GeV < E_t < 50 GeV and 6% in the region 50 GeV < E_t < 60 GeV.

CONCLUSIONS

We have measured the cross-section for production of two or more energetic jets, differential in E_T and pseudo-rapidity. A preliminary comparison with the predictions of Leading Order QCD shows good agreement.

Further work will enable us to make a quantitative comparison of the shape of the differential cross-section with Next-to-Leading Order QCD, using final systematic errors and the complete dataset collected by CDF.

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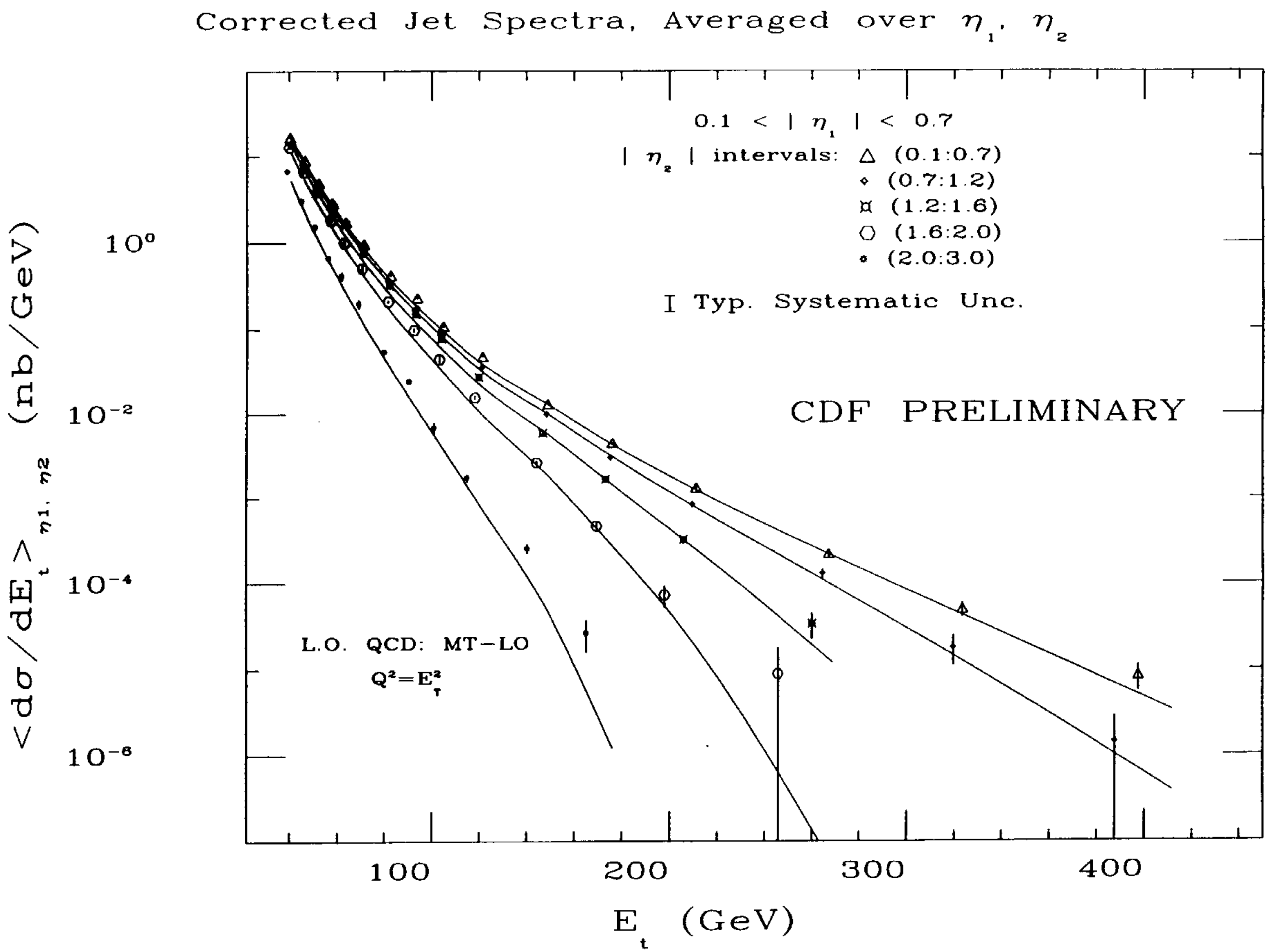

Figure 1: Corrected cross-sections for slices in η_2 with LO QCD superimposed. MT-LO structure functions and $Q^2=E_T^2$ were used. Absolute normalization. Typical systematic error indicated.

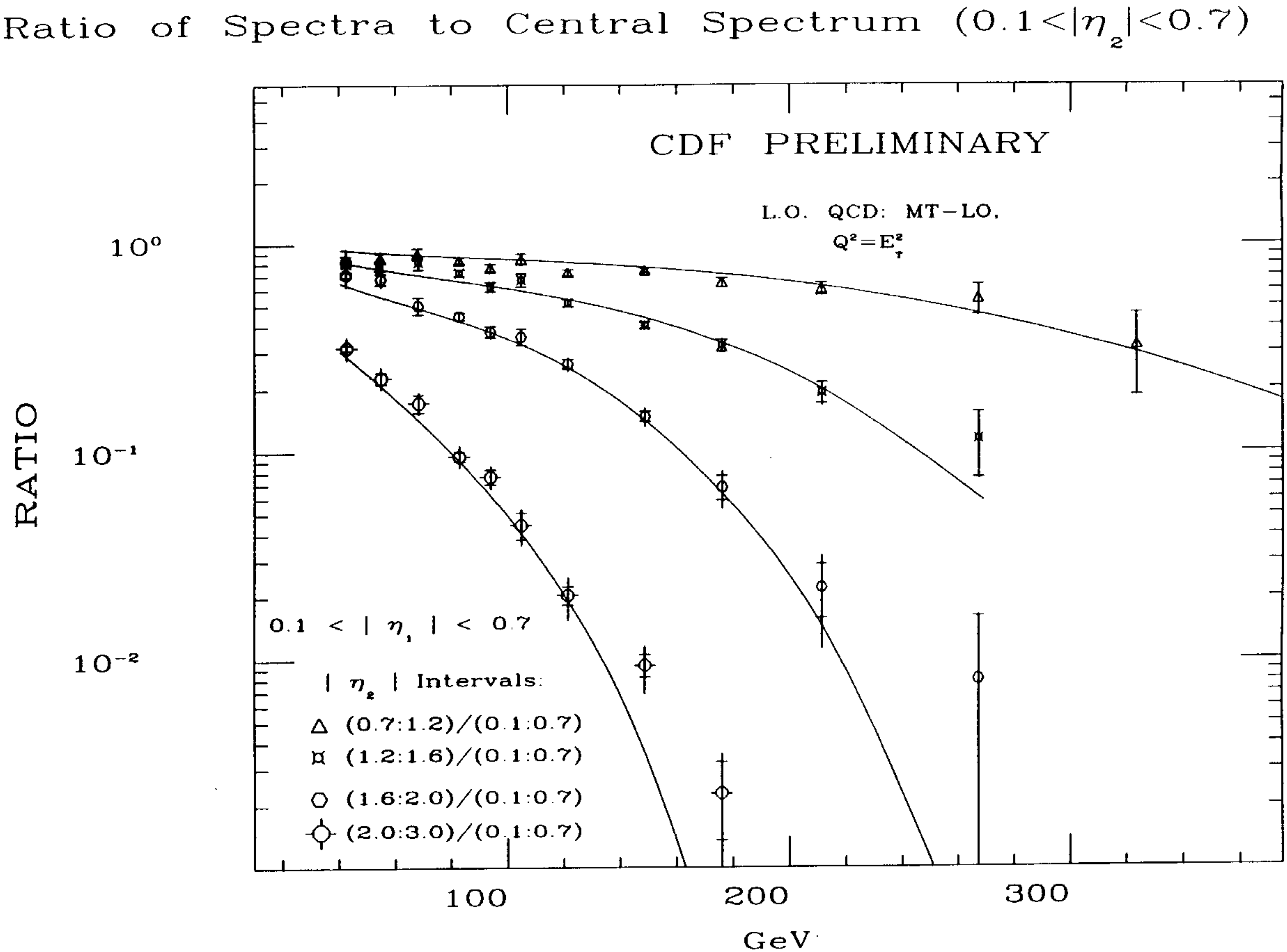

Figure 2: Ratios of corrected cross-sections for slices of η_2, with respect to the slice $0.1 < |\eta_2| < 0.7$. Also displayed are analogous ratios for the LO QCD curves of figure 1. Inner error bar is statistical, outer is combined statistical and systematic.